Measurement of shoulder abduction angles in dogs: an ex vivo study of accuracy and repeatability

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Abstract: OBJECTIVE: The aim of this study was to determine the accuracy and repeatability of the shoulder abduction test and to assess the effect of transection of the medial shoulder support structures in canine cadavers. MATERIALS AND METHODS: The shoulder abduction angle was measured by three separate observers, both with the shoulder extended and at a neutral angle. Shoulder abduction was then measured, using craniocaudal fluoroscopic images. Arthroscopy was performed in all shoulder joints, with the medial support structures transected in one shoulder of each dog. The three observers again measured shoulder abduction angles in all dogs. Shoulder abduction was measured again using fluoroscopy. Accuracy and repeatability of the abduction test were assessed using linear mixed models. RESULTS: All three observers had different measured abduction angles when compared with fluoroscopy (< 0.01); however, the experienced surgeon had an error of only 2.9°. Inter-observer repeatability was poor, with all three observers having different abduction measurements (< 0.001). Intra-observer repeatability, however, indicated no differences on repeated measurements ($= 0.26$). Placing the shoulder at a neutral standing angle, and transection of support structures caused an average increase in abduction by 8.2° (< 0.001) and 4.4° respectively. CONCLUSION: Significant variation exists between observers performing this test, increased accuracy seen in the more experienced observer. Shoulder flexion angle can significantly affect measured abduction angles.

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Running Head: Accuracy and Repeatability of the Shoulder Abduction Test in Dogs

Title: Measurement of Shoulder Abduction Angles in Dogs – An Ex-Vivo Study of Accuracy and Repeatability

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The authors of this study have no conflicts of interest to declare.

Author Contributions:

Stephen C. Jones contributed to conception of study, study design and data acquisition, analysis and interpretation. James Howard, Judith Bertran, Brittney Johnson, and Nina Kieves contributed to study design and data acquisition. Antonio Pozzi and Alan Litsky contributed to the study design. Tom Wittum performed the statistical analysis and interpretation. All authors contributed to writing and revising the manuscript and all authors approved the manuscript.

Abstract:

Objective:

To determine the accuracy and repeatability of the shoulder abduction test, and to assess the effect of transection of the medial shoulder support structures in canine cadavers.

Methods:

The shoulder abduction angle was measured by three separate observers, both with the shoulder extended and at a neutral angle. Shoulder abduction was then measured, using cranio-caudal fluoroscopic images. Arthroscopy was performed in all shoulder joints, with the medial support structures transected in one shoulder of each dog. The three observers again measured shoulder abduction angles in all dogs. Shoulder abduction was measured again using fluoroscopy. Accuracy and repeatability of the abduction test were assessed using linear mixed models.

Results:

All three observers had different measured abduction angles when compared with fluoroscopy ($p<0.01$), however the experienced surgeon had an error of only 2.9º. Interobserver repeatability was poor, with all three observers having different abduction measurements ($p<0.001$). Intra-observer repeatability however indicated no differences on repeated measurements ($p=0.26$). Placing the shoulder at a neutral standing-angle, and transection of support structures caused an average increase in abduction by 8.2º ($p<0.001$) and 4.4º respectively.

Conclusion:

Significant variation exists between observers performing this test, increased accuracy seen in the more experienced observer. Shoulder flexion angle can significantly affect measured abduction angles.

Introduction:

Shoulder instability is a well-recognized condition in veterinary medicine, and is reported to be one of the most common causes of forelimb lameness in the dog.[1-3] Instability can occur in all directions, with medial shoulder instability being the most common type of instability reported.[1,4,5] Owing to its anatomic conformation, the shoulder joint is heavily reliant on capsuloligamentous and musculo-tendinous support; the primary stabilizers of the joint medially being the medial glenohumeral ligament, the subscapularis muscle and the joint capsule.[1,4] Insufficiency of these medially supporting structures is well-documented as a cause of forelimb lameness in the dog. To date however, accurate and repeatable tests for definitively diagnosing shoulder pathology remain elusive.[2,6] While orthopaedic examination findings,[2] radiography,[1] musculoskeletal ultrasound[6] and MRI[7] all play specific roles in the diagnosis of shoulder pathology, definitive diagnosis of medial shoulder instability with these modalities remains a challenge.

Cook and colleagues described the goniometric measurement of the maximum abduction angle between the scapula and the lateral aspect of the brachium, as a method for assessing the integrity of the medial support structures of the canine shoulder joint.[8] Using this measurement technique, it was shown that dogs with medial shoulder instability had significantly higher abduction angles than those found in normal shoulder joints.[8] Interestingly in a later study, hyperabduction of the shoulder joint was found both in dogs with medial or lateral shoulder instability, suggesting a lack of specificity of the test for detecting medial shoulder instability.[6] Additionally, Devitt and colleagues found that the presence of hyperabduction had a minimal effect on the probability of finding medial compartment changes arthroscopically.[2] The study concluded that physical examination findings, including the use of the shoulder abduction test, were limited in their ability to isolate a definitive disorder responsible for the shoulder pain and lameness.[2] The findings of these studies suggest that hyperabduction is present in dogs with medial shoulder instability, but that the finding of hyperabduction is not pathognomonic for medial shoulder instability, and can be found in dogs with other shoulder pathologies.

Despite some of the conflicting findings regarding the shoulder abduction test in the literature, the non-invasive nature of this test makes its use in helping diagnose shoulder pathology appealing. In the original study by Cook and colleagues, no significant differences were found between abduction angles measured between two board-certified surgeons, or between a board certified surgeon and a senior veterinary student.[8] This suggests that this test has good inter-observer repeatability, regardless of the training or expertise of the examiner. Despite this finding, rigorous assessments of intra- and interobserver repeatability, and repeatability over time were not presented in that study. Additionally, the accuracy of the measured shoulder abduction angles was not assessed. The objectives of our study were thus to (1) determine the accuracy and (2) repeatability of the shoulder abduction test. We further aimed to (3) assess the effects of transection of the medial support structures on the measured abduction angles. Based on our clinical impressions, we hypothesized that the shoulder abduction test would have low levels of accuracy and repeatability between observers.

Materials and Methods:

Ten mixed breed dog that were euthanized for reasons unrelated to this study, with IACUC approval, were utilized. All cadavers were frozen immediately following euthanasia and thawed 48 hours prior to study commencement. Detection of any thoracic limb pathology via palpation, shoulder fluoroscopy and/or via shoulder arthroscopy resulted in cadaver exclusion from the study.

Shoulder Abduction Test

To eliminate any variability attributable to elbow joint angle, each elbow was maintained in full extension using a 3.5 mm screw, directed caudo-cranially from the olecranon into the distal humerus. Prior to data collection, the shoulder abduction test, as described by Cook and colleagues,[8] was demonstrated to the three observers performing the test. In brief, the observer stands caudal to the limb in question, one hand stabilizes the scapula by applying medial pressure over the acromion, the other hand puts the shoulder joint in full extension; the limb is then abducted until an end-point is appreciated by the observer. The angle formed between the scapular spine and the lateral aspect of the brachium is measured using a goniometer. Three observers performed the shoulder abduction test in this study: one board certified veterinary surgeon [NK], one senior resident [JB] (finishing residency and board exam-eligible at the time of data collection) and one junior resident [JH] (finishing the first year of a three-year surgical residency at the time of data collection). Each observer measured the shoulder abduction angle in both shoulder joints of all dogs 3 times. After these measurements were obtained, the shoulder joint was placed at a more neutral standing angle, defined here as 90º to the dog’s dorsal midline, and the abduction angle was again measured 3 times. This 90º angle was not measured directly, but visually approximated by the observer performing the abduction test. This was performed to assess whether variation in the shoulder joint angle, which can occur inadvertently when performing this test clinically, had any effect on the measured abduction angle. The chronological order in which each of the three observers measured the abduction angle in each dog was randomized. One difference to the previously described measurement technique[8] was that the observer performing the abduction did not read the angle on the goniometer themselves; rather, the abduction angle was read and recorded by a separate investigator [BJ, first-year surgery resident], with the observer performing the abduction blinded to the angle obtained. Measurements were recorded blindly to help prevent any bias on the part of the observer, whereby initial measurements of abduction may have influenced subsequent measurements.

Fluoroscopy and Arthroscopy

Shoulder abduction was next imaged on both limbs using continuous acquisition fluoroscopy (General Electric, OEC 9800+, Louisville, KY) at 15 frames per second, utilizing a rope and pulley system to abduct the joint, with the shoulder joint in extension. To prevent scapular abduction, a 6.5mm diameter metal rod was inserted through the scapular spine and secured in a plexiglass jig **(Figure 1).** This rod was placed underneath the supra- and infraspinatus muscles, entering the scapular spine immediately proximal to the acromion, at an angle approximately perpendicular to the scapular spine. The scapulo-humeral joint angle for each joint was then measured using the cranio-caudal fluoroscopic images, using commercially available software (Sound-Eklin, Carlsbad, CA) **(Figure 2).** The largest angle formed between the scapula and humerus on the fluoroscopic images was taken as the abduction angle. Shoulder arthroscopy was then performed on all joints by one investigator [SCJ] with the dogs positioned in lateral recumbency. A lateral port immediately distal to the acromion was used for arthroscopic access; a second cranio-medial port located between the biceps tendon cranially and the subscapularis tendon caudally, was used for instrument access. Either the left or the right shoulder joint was randomly selected to have the subscapularis tendon and the medial glenohumeral ligament transected; the other joint was also assessed arthroscopically but had no other intervention performed. Using the cranio-medial port, tissue transection was performed using a number eleven scalpel blade. In the majority of the shoulders, the caudal band of the medial glenohumeral ligament and portions of the subscapularis tendon were enveloped in the joint capsule. Thus, in all of the treated joints, some of the medial joint capsule was also transected to ensure complete release of the supporting structures. The subscapularis tendon and medial glenohumeral ligament were probed following sectioning to confirm completeness of their release. Following arthroscopy, each observer again measured the abduction angle in all shoulder joints three times. All three observers measuring the abduction angle were blinded to the interventions performed in each dog via arthroscopy. Finally, to assess the effects of measurements over time all dogs had the abduction angle recorded a second time using the same fluoroscopic technique; in all dogs this was performed on the same day as the initial abduction measurements.

Data Analysis

Statistical analyses were performed using a computer software system (JMP Pro Version 12.2.0). Abduction angle outcome data were evaluated for normality using standard graphical methods.[9] As is customary in clinical cases, each observer measured the abduction angle of each shoulder three times and the average of these measurements were used for the statistical comparisons. Accuracy was determined by comparing the observers' measurements with the measurements obtained from the fluoroscopic images, via a linear mixed model. The model utilized the untransformed abduction angle as the outcome of interest. The observer, extension of the limb, and treatment were considered as main fixed model effects. Inter-observer repeatability was assessed by comparing the goniometric measurements made in extension, across the three examiners prior to arthroscopy. The ten pairs of shoulders were treated as independent measurements (n=20), with the limb within dog as a random effect. Multiple pairwise comparisons of least squares (LS) means used the Tukey-Kramer adjustment of p-values. The interaction of observer and repeated observation within the linear mixed model was used to evaluate intra-observer repeatability, for the subset of joints that had not been treated. A total of 20 goniometry measurements were thus obtained (10 at the first examination; 10 at the second examination). The impact of treatment and of shoulder position (extension versus neutral) on abduction angle were also assessed using a linear mixed model, with limb within dog as a random effect. Significance was set at a p-value <0.05.

Results:

The weight of dogs ranged between 18-39 kg, with the mean (± SD) weight being 28.7 kg (± 6.9kg). No thoracic limb pathology was detected on examination, fluoroscopy or during shoulder arthroscopy. The outcome of interest, abduction angle, was determined to be normally distributed using standard graphical methods.

Accuracy

The average abduction angle measured, for all dogs by all three observers were significantly different to the measurements obtained using fluoroscopy (**Table 1**). Because of the large observed inter-observer variability in abduction angle measurements, accuracy was also assessed independently for each observer using separate linear mixed models. Again, measurements from all three observers were different to the fluoroscopy measurements ($p<0.01$). Of the three observers, the board-certified surgeon's abduction value (27.2º) was the closest value to that obtained via fluoroscopy (30.1º). The senior resident had an abduction angle measurement 8.3º higher, while the junior resident had an abduction angle measurement 9.5º lower, than the abduction measurement obtained via fluoroscopy.

Repeatability

When assessing inter-observer repeatability, all three observers had different shoulder abduction angle measurements ($p<0.001$) (**Table 1**). However, we did not detect an intra-observer difference for any of the three observers, over the two times measurements were made by each observer, both with the shoulder in extension ($p=0.26$) and in neutral position ($p=0.51$).

Effect of Limb Position and Tissue Transection

Because of the large observed inter-observer variability in abduction angle measurements, the effect of limb position and tissue transection was also assessed independently for each observer using separate linear mixed models. After controlling for limb within dog, measurements taken in extension and neutral position were found to be different ($p<0.001$) for each observer. Placing the limb in a neutral (standing angle) position, increased the predicted abduction angle by an average (± SD) of 8.2º (±2.0º) for all three observers, when compared with the shoulder in extension. Transection of the medial support structures increased the abduction angle by an average (± SD) of 4.4º (±4.9º) for all three observers. However, measurements taken pre-and post-treatment were only significantly increased ($p<0.001$) for the senior resident, and not for the junior resident or the surgeon (**Table 2**).

Discussion:

Based on our results, we accept our hypothesis that the shoulder abduction test is not as accurate as the fluoroscopic measurement. However, it should be noted that the average measurements obtained by the experienced surgeon differed only by 2.9º from fluoroscopy, a non-clinically relevant error. The basis of this test relies on the ability of the observer to detect the physiologic end-point of shoulder abduction. Perhaps, more familiarity with this test improves the observer's recognition of this abduction end-point, thereby increasing test accuracy. While the observer performing the test clearly plays an important role in test accuracy, our accuracy results should also be interpreted in terms of clinical relevance. The reported values of abduction angle associated with medial shoulder instability are ~20º higher than the normal values reported here.[8,10] While the shoulder abduction test may not be accurate based on a gold standard measurement, the test may be accurate enough for detecting clinically relevant hyperabduction angles.

We also accept our hypothesis that the shoulder abduction test has poor inter-observer repeatability, suggesting that the three observers had a different interpretation of the physiologic end-point to shoulder abduction. Using the fluoroscopic images, we found that there truly was an end-point to shoulder abduction; continued abduction beyond this point (via pulling on the rope) resulted in the proximal end of the scapula rotating towards the body wall, with no continued increase in the scapulo-humeral abduction angle noted. The results of this study show that this end-point may be challenging to discern clinically, especially for less experienced clinicians. With dog 5 for example, the variation between the average abduction angle measured by the senior resident (53º) and the junior resident (17º) was 36º. Given that the normal shoulder abduction angle in dogs is ~32º,[6,8,10] caution should be exercised in interpreting abduction angles made in the same animal by two different observers.

No significant differences were detected between repeated abduction angle measurements made by each of the three observers; we therefore reject our hypothesis of poor intra-observer repeatability. Each observer performed the test very similarly throughout the experiment, with the senior resident consistently having the highest abduction measurements and the junior resident consistently having the lowest abduction measurements (**Tables 1 and 2**). This finding suggests that muscle memory and the amount of force used by each observer during the abduction test may have influenced what each observer perceived as the abduction end-point and ultimately their measured angles. Based on this intra-observer repeatability, an individual observer may be repeatable in their interpretation of abduction angle measurements in a clinical patient over time. Additionally, comparing the abduction angle to the contralateral normal shoulder may be a valuable test, because the clinician will apply a similar force to both shoulders. While we did assess repeatability over two-time points in these cadaveric specimens, both measurements in each cadaver were taken on the same day, separated by a number of hours. Further studies are needed to assess intra-observer repeatability over more extended time periods, similar to what would be seen clinically in patients that are presented for re-examination, weeks to months later.

Interestingly, placing the shoulder in less extension and into a more neutral/standing angle resulted in a mean increase in the measured abduction angle by approximately 8º (±2.0º). Cook and colleagues described performing the abduction angle measurement test with the shoulder in full extension.[8] Accounting for standard deviation, the mean shoulder abduction angle measurement for normal dogs in that study, ranged from ~30-35º.[8] Given the increased abduction angle seen with performing the test at a more neutral shoulder angle, it is possible for a normal dog with a naturally higher abduction angle to be misinterpreted as having a hyperabduction angle. This finding highlights the importance of maintaining the shoulder in extension when performing this test clinically. It must be said that no attempt was made to quantify the amount of shoulder extension that each observer used during measurement in this study. Notwithstanding this limitation, all observers were instructed to have the shoulder in full extension for performing the main analyses (as per Cook and colleagues[8]) and to then to bring the humerus into a more neutral standing angle for the second abduction analysis. Clinically, if shoulder extension is not maintained, similar results could occur and thus, the observer should pay close attention to maintaining full shoulder extension when performing this test.

Transection of the medial supporting structures of the shoulder joint, resulted in only a limited increase in the abduction angle, over all observers. While the abduction angle measured post-treatment (average post-treatment abduction - 36.2º) did increase when compared to the pre-treatment values (average pre-treatment abduction - 31.8º), the angles measured were not consistent with the hyperabduction angles reported in the literature for dogs with medial shoulder instability. Cook and colleagues found dogs with medial shoulder instability to have abduction angles in the 50-54º range.[8,10] A later study by Cogar and colleagues had similar findings whereby dogs diagnosed with medial shoulder instability had significantly higher abduction angles than normal dogs.[6] As mentioned previously however, that study also found that dogs with lateral shoulder instability were equally likely to have hyperabduction of the shoulder as the dogs with medial shoulder instability.[6] In reality, atraumatic medial shoulder instability in dogs remains poorly described, with a consensus on incidence rates, appropriate diagnostics and treatment protocols lacking and sometimes contradictory, in the veterinary literature. The hyperabduction angles seen in previous in-vivo studies, may in part be explained by the muscle atrophy that was seen in those clinical patients.[6,8,10] We should not however neglect the possibility that the differences in abduction values between our study and the hyperabduction values detected in these previous studies were due to measurement inaccuracies on our part, were an artifact of the previously frozen cadaveric tissue or were secondary to incomplete transection of the medial support structures.

The findings of the data in this study should be interpreted in light of several important considerations. Firstly, it remains possible that in the hands of certain individuals, measured abduction angles might be both accurate and clinically relevant. Specifically, the data showed that the surgeon was the most accurate of the observers in this study with a mean bias between her measurements and those obtained using fluoroscopy of just 2.9 degrees. This small difference may not render the shoulder abduction angles clinically irrelevant. The study is also limited in that it did not evaluate inter-observer reliability among multiple individuals of similar experience or skill level, most notably board-certified surgeons. Consequently, we cannot definitively conclude that inter-observer repeatability among observers with increased training is poor. Some of the accuracy data may be influenced by errors in our established gold standard of fluoroscopy. Although we attempted to ensure that fluoroscopic images were captured exactly perpendicular to the humerus and scapula, motion during abduction may have resulted in some imperfect positioning of the limb with respect to the fluoroscopic beam. Arthroscopic transection of the medial support structures of the shoulder does not replicate the natural course of medial shoulder instability in-vivo. Furthermore, no attempt was made to grossly reexamine the specimens after the study, to assess completeness of ligament and tendon transection. Results would have been affected by any shoulder joints that did not have complete transection of the structures arthroscopically. It is worth stating however, that with transection of the medial joint capsule, we felt that it was easy to see the subscapularis and medial glenohumeral ligament and to assess the completeness of their transection arthroscopically. Lastly, each elbow in this study was fixed in extension using a screw. This was to ensure the elbow position was the same during the observers' abduction testing and during fluoroscopy, thus eliminating this as a variable factor. However, in-vivo the observer must manually extend and maintain the elbow joint in extension throughout the abduction test. Eliminating this may have affected the overall reported accuracy and repeatability.

In conclusion, the shoulder abduction test may have some limitations that could influence accuracy and repeatability of the measurements. Caution should be exercised when using such values to direct clinical decision making, especially when performed by a less experienced clinician. We additionally caution against using measurements from this test as a definitive outcome measure to assess response to treatment, particularly if different observers are performing the test. Given that measured abduction varied with different shoulder flexion angles, we recommend ensuring the shoulder is consistently held in full extension when assessing the abduction angle, especially when comparing measurements in the same patient over time.

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Figure Legends:

Figure 1: Dog is positioned in lateral recumbency. Cranio-caudal fluoroscopic images were obtained as the shoulder joint was abducted, using a rope and pulley system. Note that the elbow joint is maintained in extension, with the shoulder joint positioned in full extension prior to and during image acquisition. The scapula is secured to the plexiglas jig using a metal rod inserted through the scapular spine.

Figure 2: Cranio-caudal fluoroscopic images before abduction (A) and at maximal abduction (B). A straight line was best-fitted to the length of humeral diaphysis that was visible on the fluoroscopic image, and the visible portion of the scapular spine, at maximal abduction. The acute angle measured at the intersection of these two lines represented the shoulder abduction angle. Note the radiopaque object towards the top of the image is the metal bar securing the scapula. The radiopaque object near the bottom is a metal bracket and screws securing the plexiglas jig.

Tables:

Table 1: Least Square (LS) mean abduction angles for each observer and fluoroscopy from the linear mixed model. Note – Levels not connected by the same letter are significantly different

Table 2: Least Square (LS) mean abduction angles for each observer when the shoulder was held in extension (Ext) and in neutral (Neu); and before (Pre) and after (Post) transection of the medial shoulder support structures. Note that in all three observers, the LS Mean shoulder abduction angle was significantly higher when the test is performed with the shoulder at a more neutral flexion angle.